

## The Flow Visualization Facility

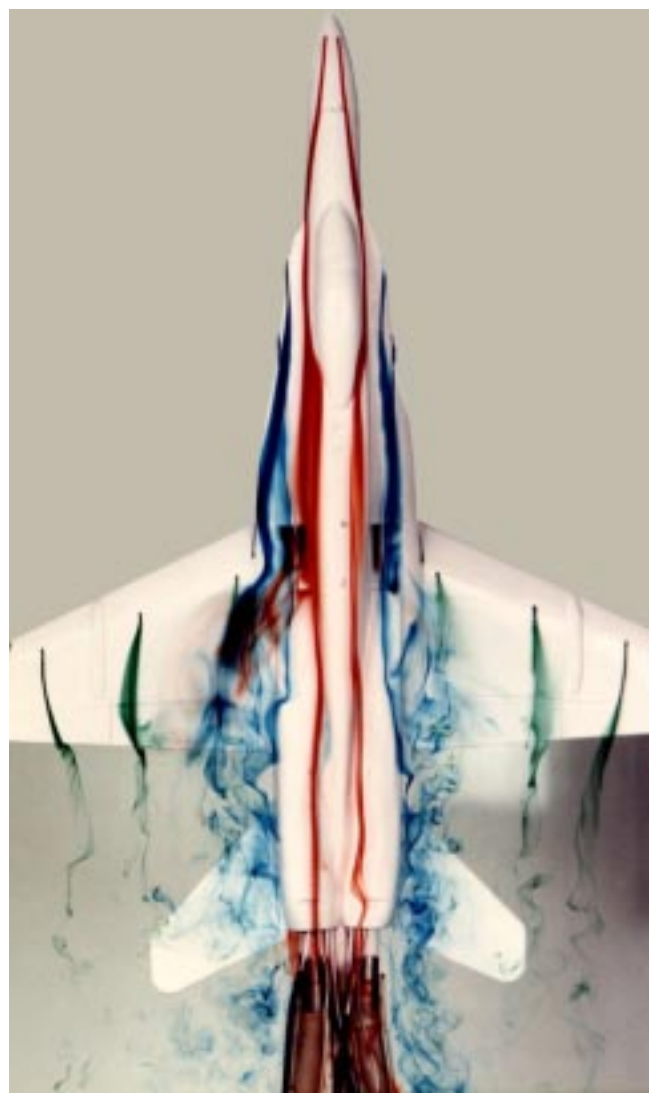
### "Dryden's Water Tunnel"

Aeronautical engineers at the NASA Dryden Flight Research Center often use water to help make aircraft fly more efficiently and safer.

The water is used in a closed-circuit Flow Visualization Facility (FVF) commonly called "the water tunnel." The facility helps engineers understand the characteristics and effects of air flowing over and past an aircraft or an aircraft component by using water to simulate air. The water flow patterns are studied and recorded in nearly the same way that wind tunnels are used.

Water tunnels have become a very useful diagnostic tool in the development of advanced technology aircraft. Although the FVF is much smaller than most wind tunnels, it can produce three dimensional test results which compare well to actual flight data, but at a much lower cost than a wind tunnel and the FVF tests can be conducted in considerably less time.

Water tunnels such as the one at Dryden are used as a "first step" in providing important information about anomalies and phenomena revealed in wind tunnel tests or in actual flight tests. Water tunnels are also used to study and improve new aircraft and hardware designs. After test results are studied carefully and understood,



*Colored dye emitted from tiny ports on this 1/48 F-18 model displays the vortex flow field during tests in the Dryden Flow Visualization Facility.*

NASA Photo ECN 33298-36

possible configuration changes on the full-size aircraft can then be considered.

To observe the flow fields and vortices created in the water tunnel, colored dye is injected into the moving water from tiny ports on aircraft models and models of flight hardware. The dye creates a visual three-dimensional image of vortices and flow fields around the test object that can be photographed and recorded on video cameras for subsequent studies. Laser light sheets and shadowgraphs are also used to accommodate photography and video taping in the FVF.

Most of the tests conducted in the FVF have been to study aerodynamics associated with high-angle-of-attack research such as determining the strength and location of vortex flows at various flight attitudes. Angle of attack (AOA) refers to the angle of an aircraft's wings or fuselage relative to the direction in which the aircraft is moving through the air. Wings produce less lift as AOA increases and soon an aircraft can easily become uncontrollable. NASA studies involving high AOA sought better means of controllability at extreme angles of attack. At Dryden, the FVF contributed significantly to the early development of AOA research projects.

Among the aeronautical projects the FVF has supported are the F-18 High Angle of Attack Research Vehicle (HARV), the F-8 Oblique Wing research aircraft, the Space Shuttle, the Air Force YF-22, the X-33, the SR-71, hypersonic vehicle research in which speeds of over Mach 4 were simulated, vortex studies on F-14, F-15, and F-16 aircraft, and high AOA studies of vertical/short takeoff and landing (V/STOL) aircraft.

The facility was used to support the Space Shuttle drag chute verification program at Dryden, and also to study flow fields on lifting body models during development of the X-38. The X-38 was the

proposed space station crew return vehicle that incorporated the wingless lifting body concept.

Other uses of the FVF include flow field studies of flight hardware such as pylons, air probes, antennas, and other similar fixtures that would disturb airflow during flight. The FVF has also been useful in helping to determine the best locations for smoke emission devices on a research aircraft being used for in-flight atmospheric flow visualization studies.

## **FVF Description and Operation**

Dryden's FVF was built by NASA in 1983 and is patterned after the Northrop Corporation water tunnel in Hawthorne, Calif. It was designed to consume a minimum of floor space, a factor that resulted in a vertical orientation of the facility's three main structural components -- a vertical test section, a horizontal test section, and the settling tank. The other main component is the pumping system located at ground level.

The vertical test section is a four-sided chamber 6 feet high, 16 inches deep and 24 inches wide. It is constructed of 2-inch clear acrylic plastic on all sides so that tests can be observed from nearly all angles. A round 16-inch door on the outboard 24-inch side gives personnel access to the interior for model mounting and test preparation.

The horizontal test section is 77.5 inches high and 24 inches wide. Visual and physical access to the horizontal unit is limited because the top of the chamber is more than 15 feet above the floor and access must be from above. The horizontal chamber is very suitable as either a free-surface channel or as a water table by using a sluice gate on the "upstream" end of the section. The distance the sluice gate is open, combined with adjusted pump speed, can adjust the flow rate. During shadowgraph

photography in the horizontal chamber, conditions simulating supersonic and hypersonic speeds can be created and studied.

The largest part of the FVF is the 15.5-foot high, 24-foot wide stainless steel settling tank. When the FVF is operating, a 15-hp electric centrifugal pump sends water into the bottom portion of the settling tank through a 12-inch pipe. The water enters the settling tank through a series of small holes drilled around the perimeter of the entry pipe to reduce turbulence created by the pumping action.

Pumping action forces the water to rise and flow across the upper portion of the settling tank into a smaller horizontal section where it passes through two honeycomb flow straighteners that stabilize the flow and eliminates turbulence. The horizontal test section is that portion of the upper channel between the two flow straighteners.

After passing through the horizontal section, water flows down past a third honeycomb straightener and enters the vertical test section. The water exits the bottom of the test section through an 8-inch return pipe and is carried back to the centrifugal pump for continuous recirculation. On the “upstream” side of the pump is a diatomaceous earth filter that constantly cleanses the water.

The velocity rate of the water can be varied from 2 to 10 in. per second, based on the type of test being carried out. Experience has shown that a velocity rate of slightly more than 3 in. per second generally provides the best visualization results, with minimal water turbulence, for most tests.

## Test Models

Models used in the FVF are typically scaled 1/32 and 1/48. Commercial plastic model kits are often used if a model of the real aircraft associated

with the test project is available. Commercial plastic models are excellent tools for use in the FVF because they are usually very accurate in depicting design configurations and their price tags helps keep operational costs low. The loads on the models created by the dynamic pressure of the water are low and eliminate the danger of breakage in most cases.

The model kits are assembled in the Dryden model shop where technicians carefully prepare their surfaces to assure that test data isn’t compromised by imperfections. The models are supported inside the test chamber by an attachment called a sting.

Once model shop technicians identify where the dye injections lines are located they are installed before assembly is complete. The external ports must be flush with the model’s surface so the flow of the dye will not affect the model’s flow field.

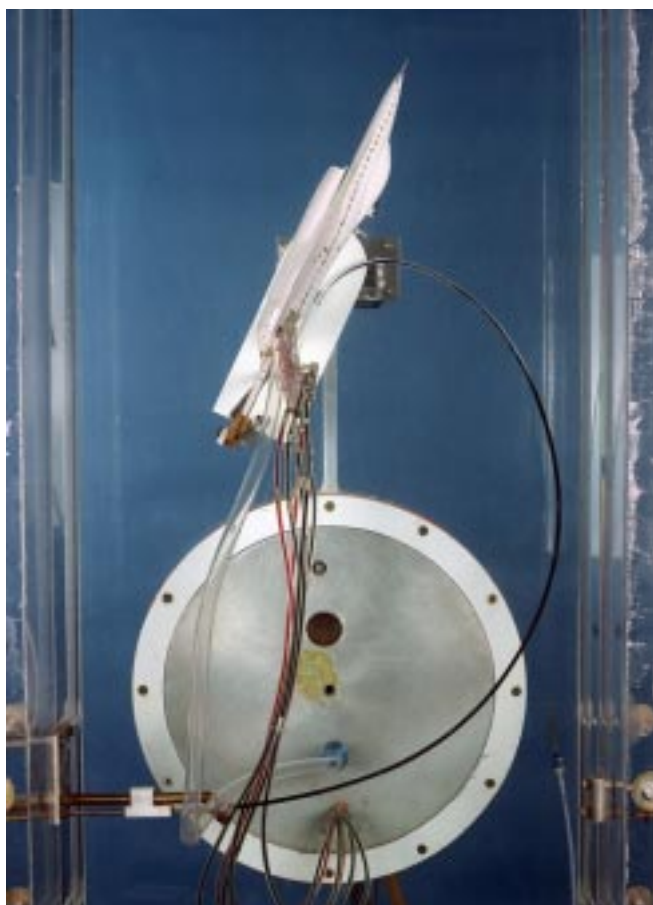
On most models of jet aircraft tested in the FVF the engine inlets are open and water is allowed to enter to create the simulation of mass flow through the engine or engines. The water passes through the inlet and is then ducted away from the test section so it doesn’t disturb the flow field. During tests where water flows into the inlets, the flow rates in the test chamber and the inlet are carefully coordinated to correspond to specific flight conditions.

Engine exhaust streams are also modeled in the same fashion by ducting water from outside the test chamber into the model and out the exhaust outlet. Water flow in the test chamber and inside the model is coordinated much like the inlet flow to correspond to realistic flight conditions.

Model shop craftsmen also make models of specialized test hardware and components when they are not available from another source, such as pylons, air probes, antennas, and other fixtures that would

disturb airflow during flight.

The size of the models tested in the FVF are limited by the dimensions of the test chambers, but researchers prefer large models over small ones because they usually yield more accurate test data and visual flow details are more easily studied.



*The model support system and dye lines are seen in this photo of a model mounted in the vertical test section of the Dryden Flow Visualization Facility, as viewed from the pitch axis.*

*NASA Photo EC9442399-10*

Most of the tests carried out in the FVF are for visual purposes and still photos and videotape are the primary means of acquiring visual documentation of tests results. The video system, using  $\frac{1}{2}$ -in. tape, includes a text generator that creates title screens and displays test conditions. A video screen splitter allows the camera to record the platform of the test article and side views simultaneously.

Model positioning in the FVF is controlled by a computerized system that includes a motion controller, servomotors, a joystick, and a model support arm inside the test chamber. A model's angle of attack and yaw angle (in relation to the direction of water flow) can be adjusted by either moving the joystick or by entering the desired position into the computer. As position inputs are made, a character generator linked to the video camera system records the new position on videotape. A typical model 18-in. long will have an angle-of-attack range of -30 degrees to +90 degrees. The yaw angle will usually be limited to about 15 degrees because of wingspans.

## Dye Injection System

The use of colored dye is the most common means of producing flow visualization in the FVF. It is commercial vegetable-based food coloring found in most any grocery store.

The dye is emitted into the water from flush ports, external tubes, probes or any other means that will allow it to be captured by the flow field being studied.

A system of six pressurized dye containers is mounted on the outside of the test section. Each can hold a different color and the rate of flow at each container are controlled by individual needle valves. Dye feed lines from the containers are placed in the test chambers and attached to the models in the vertical test section through the side door.

Individual test requirements determine how the dye lines are configured and how many are used. Each dye line can be routed to many smaller lines through a manifold system. Tests in the FVF have seen as many as 120 dye lines being used simultaneously.

## Laser Light Sheets

Laser light sheets are used to visualize the cross section of a flow field.

Either fluorescent dyes or a particulate such as aluminum powder is placed in the flow field “upstream” to act as a tracer element. A thin but broad sheet of laser light is used to illuminate the tracer element at a particular location in the flow field, based on test requirements.

The tracer elements give off a brilliant pattern in the flow field as the laser light sheets illuminate them.

During the tests, the laser light sheets can be moved and scanned across the model, they can be oriented vertically or horizontally, and are easily photographed or recorded on videotape.

## **Shadowgraph Photography**

The horizontal test chamber is normally used for tests that call for a free surface water table where conditions will allow simulated supersonic and hypersonic speeds to be visually recorded.

For these tests, two-dimension models are placed on the bottom of the test chamber that is painted white. Cameras and lights are placed above the test chamber. The flow rate is controlled by placement of the sluice gate and a coordinated pump speed. Shadows of waveforms -- analogous to

atmospheric shock waves -- are created on the chamber floor by overhead lighting and can be easily photographed.

Simulated Mach numbers of 4.10 have been created in the horizontal test chamber during past studies of high-speed flight vehicles.

## **FVF Benefits**

The Dryden FVF has become a convenient, inexpensive, and accurate research tool for project personnel who need to study fluid dynamics phenomena in connection with advanced technology vehicles, especially those associated with high angle-of-attack flight.

The facility allows flow field visualization and interpretation in a timely and cost-effective environment, factors that are becoming increasingly important as aerospace vehicles become more complex and expensive.

Advancements in model construction and instrumentation, along with increased knowledge of the behavior of fluids, will give the Dryden FVF an even more important role in NASA’s quest to keep the United States at the forefront of world aviation.